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Guided crowd dynamics via modified social force model

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HIGHLIGHTS

- Modification analysis of the social force model is presented.
- Modified social force model is used for guided pedestrian dynamics.
- Some social phenomena like gathering, balance and conflicts are observed.
- Time delay for pedestrians with time-dependent desired velocities is observed.
- Predictive evacuation experiments are carried out using the guided crowd model.

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ABSTRACT

Pedestrian dynamics is of great theoretical significance for strategy design of emergency evacuation. Modification of pedestrian dynamics based on the social force model is presented to better reflect pedestrians' behavioral characteristics in emergency. Specifically, the modified model can be used for guided crowd dynamics in large-scale public places such as subway stations and stadiums. This guided crowd model is validated by explicitly comparing its density–speed and density–flow diagrams with fundamental diagrams. Some social phenomena such as gathering, balance and conflicts are clearly observed in simulation, which further illustrate the effectiveness of the proposed modeling method. Also, time delay for pedestrians with time-dependent desired velocities is observed and explained using the established model in this paper. Furthermore, this guided crowd model is applied to the simulation system of Beijing South Railway Station for predictive evacuation experiments.

1. Introduction

The development of pedestrian dynamics for emergency evacuation is an ongoing research area in traffic science and engineering. A strong interest in this topic since the early 1990s has shown the significance of this issue [1]. Generally, in public places such as subway stations and airports, an evacuation system is an important component of the safety requirements. A good evacuation system could avoid catastrophic consequences in an emergency. Therefore, predictive pedestrian simulation of the evacuation system is essential for infrastructure designs in the planning under certain conditions which take place in different buildings or circumstances.

The dynamic features of pedestrian evacuation such as lane formation, clogging effect, stop and go waves, herding and zipper effect have been observed and successfully regenerated by various pedestrian dynamics models, which mainly fall into two categories: macroscopic level and microscopic level [2]. One of the classical macroscopic model is the fluid dynamics model treating pedestrian dynamics as a fluid with the use of partial differential equation, where the dynamic characteristics

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of the crowd flow are described by average speed, density, location and time. Hughes [3] studied the problem of route choice by using a continuum model based on well-defined observations of pedestrian behavior. Colombo et al. [4] presented a continuum model able to describe features of the possible over-compressions in a crowd and the outflow through a door of a panicking crowd jam. Even though the macroscopic model could describe the overall movement trend of the crowd, detailed behaviors and interactions of the crowd will be overlooked. This is one reason why we do not choose the macroscopic model to study pedestrian dynamics characteristics in this paper.

Unlike macroscopic models, microscopic models are state of the art for computer simulation of pedestrian dynamics which put particular emphasis on the mutual influence of individuals. Hirai and Tarui [5] in the 1970s proposed a mathematical force model which consisted of some forces trying to capture several crowd movement factors like mass psychology and wall configurations. Cellular automata [6] is a discrete dynamic system belonging to a microscopic model with grid-based motion decision. The lattice gas model [7] is a special case of cellular automata based on means of probability and statistics. The social force model [8] is also a microscopic model, but this model is in a continuous space and introduces a desired force to describe the inner drive of pedestrians to escape, especially under the stressful situations. Nomad [9], a generalization of the social force model, incorporates a strategic decision making process unlike the original social force model. The agent-based model [10] which simulates pedestrians with virtual agents establishes the social structures from the "bottom-up", but it usually costs more computation [2]. The game theory model [11] is often adopted to the rational pedestrian evacuation by maximizing each evacuee's utility.

Considering all the above microscopic models' characteristics, we choose to use the social force model as the basic model to study the crowd dynamics. There are several reasons for that. One is that the social force model could qualitatively reproduce some self-organizing phenomena like lane formation and arching [12], which is suitable for describing low density crowd dynamics that can meet our demand. Another reason is that the discrete space model like cellular automata or lattice gas model which makes pedestrians walk at or within a fixed node or grid cannot allow pedestrians to move around in an unrestricted manner that is not in line with reality [13]. The social force model as a continuous space model, however, allows pedestrians to move continuously within a pre-defined place by defining some forces like the desired force. Also, the social force model considers both physical and motivation forces that is believed to be convenient for importing psychological and sociological factors into Ref. [14].

Helbing et al. introduced the vision field by defining a term to the socio-psychological force in the original social force model that could reflect the anisotropic character of pedestrian interaction [15], and they also proposed that the desired speed increased in the course of time to compensate for delays by considering the average speed into the desired direction of motion [16]. In Ref. [16], the desired velocity fluctuated only according to the realization degree of desired velocity itself which reflected the nervousness or impatience. In reality, the desired velocity, however, could also be affected by pedestrians around and the surrounding environment. If pedestrians around have a higher mean speed than that of the current pedestrian or the atmosphere is very tense reflecting from the surrounding environment such as annunciators keep ringing, pedestrians who become nervous will change their motivation or excitement degree accordingly. Therefore, in this paper we are going to do some further modification work directing at the desired velocity to make pedestrians have a sensitive response to surrounding pedestrians and environment, and become more reality.

It is a rather common phenomenon that pedestrians are unfamiliar with the area where they are and insensible of positions of exits, especially when they are too scared to keep sober-minded in emergencies. At present, the role of a guide who rescues them from emergencies is very important for scared people. With the improving awareness of safety, many inspection staff, who may act as guides in an escape, are arranged within a certain range of the large-scale public places to be responsible for safety inspection.

Guided pedestrians usually show special psychological states and complex interactions between each other in emergencies, and the actual observed movement in emergency has obvious nonlinear characteristics [17]. Group dynamics emerges during the escape, showing the characteristics of the group such as gathering, conflicts and balance [18]. Although much research on simulations of pedestrians' movement in emergency has been conducted, little research focuses on the movement of groups, especially groups with guide in the large-scale public places [19]. Generally, modeling a group with guide is essential for the further study of evacuation. It is high time that we should establish a model to reflect the group dynamics aspects.

The rest of this paper is as follows. A modification method of pedestrian dynamics is proposed based on the social force model in Section 2, which considers that the desired velocity is influenced not only by the realization degree of desired velocity itself but also by the surrounding people and the surrounding environment. Section 3 applies the modified pedestrian dynamics model to the guided pedestrian group. Section 4 verifies the crowd dynamics model by comparing its density–speed and density–flow diagrams with fundamental diagrams and studies the effects of the guide for the evacuation crowd, as well as analyzes the effect of desired velocity on the evacuation time through a large number of simulations. In Section 5, evacuation experiments with multiple guides are done based on the simulation system of Beijing South Railway Station.

2. Modification of the social force model

2.1. Social force model

The social force model was proposed by Helbing et al. [12], where the pedestrians are driven by three forces: the desired force, $\vec{f}_i^{\,0}$; the interaction force between pedestrians i and j, $\vec{f}_{ij}$; and the interaction force between pedestrian i and walls, $\vec{f}_{iw}$.

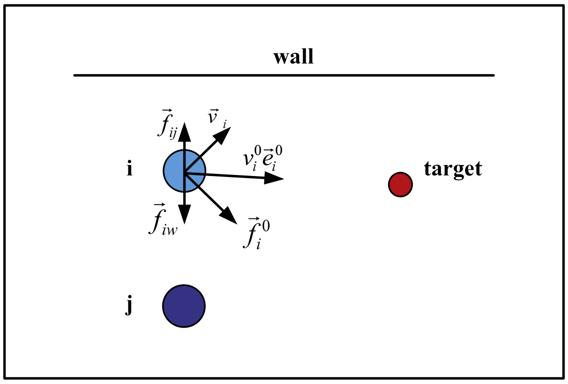

Fig. 1. Diagram of the social force model.

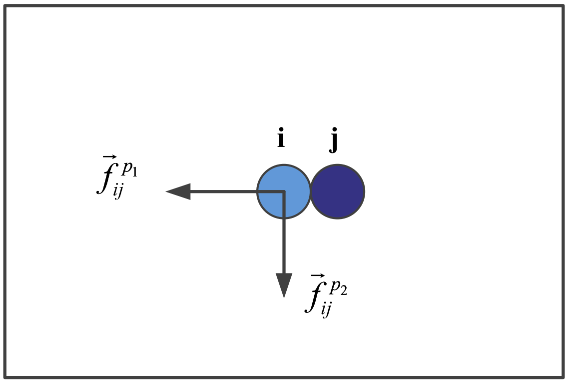

Fig. 2. Diagram of the physical force.

According to Newton's second law of motion, the corresponding mathematical expression of each pedestrian i is

$$m_i \frac{d\vec{v}_i(t)}{dt} = \vec{f}_i^0 + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_{w} \vec{f}_{iw}, \tag{1}$$

where m_i is the mass of pedestrian i, and $\vec{v}_i(t)$ is the actual walking velocity.

In this social force model, the diagram of desired force, $\vec{f}_i^0$, interaction force between pedestrians i and j, $\vec{f}_{ij}$, and interaction force between pedestrian i and walls, $\vec{f}_{iw}$, are given in Fig. 1.

2.1.1. Desired force

The desired force, $\vec{f}_i^0$, reflects the pedestrian's willingness to achieve the desired velocity. This force can be expressed by the following form:

$$\vec{f}_i^0 = m_i \frac{v_i^0(t)\,\vec{e}_i^0 - \vec{v}_i(t)}{\tau_i}, \tag{2}$$

where v_i^0 is the desired speed with a certain direction $\vec{e}_i^0$, and τ_i is a constant of adaptation time to adjust pedestrian's actual walking velocity.

2.1.2. Interaction force between pedestrians

The interaction force between pedestrians i and j, $\vec{f}_{ij}$, mainly contains socio-psychological force, $\vec{f}_{ij}^s$, and physical force, $\vec{f}_{ij}^p$. The psychological tendency between pedestrians i and j to stay away from each other is expressed by the repulsive interaction force, $\vec{f}_{ij}^s$, which obtains its maximum value when two pedestrians have the minimal distance. The physical force exerts on people when the distance between two pedestrian centers, d_{ij}, is less than the sum of the radii of these two pedestrians, $r_{ij} = r_i + r_j$. The physical force shown in Fig. 2 contains "body force", $\vec{f}_{ij}^{p_1}$, to counteract the body compression, and "sliding friction force", $\vec{f}_{ij}^{p_2}$, to hinder the relative tangential motion. The corresponding expression has the following form:

$$\vec{f}_{ij} = \vec{f}_{ij}^s + \vec{f}_{ij}^p, \tag{3}$$

Table 1
Parameters of the social force model.

Symbol	Meaning	Value
m	Pedestrian mass	80 kg
r	Pedestrian radius	0.25 m
A	Strength of social repulsive force	2000 N
B	Characteristic distance of social repulsive force	0.08 m
κ	Coefficient of sliding friction	240000 kg m^{-1} s^{-1}
k	Body compression coefficient	120000 kg s^{-2}
τ	Pedestrian reaction time	0.5 s

where

$$\vec{f}_{ij}^{s} = A_i \exp\left[\left(r_{ij} - d_{ij}\right)/B_i\right]\vec{n}_{ij}, \tag{4}$$

$$\vec{f}_{ij}^{p} = \vec{f}_{ij}^{p_1} + \vec{f}_{ij}^{p_2} = kg\left(r_{ij} - d_{ij}\right)\vec{n}_{ij} + \kappa g\left(r_{ij} - d_{ij}\right)\triangle v_{ji}^{t}\vec{t}_{ij}. \tag{5}$$

Here, A_i, B_i, k, κ are constant parameters. $\vec{n}_{ij} = (n_{ij}^1, n_{ij}^2) = (\vec{r}_i - \vec{r}_j)/d_{ij}$ is the unit vector pointing from pedestrian j to pedestrian i, among which $\vec{r}_i$ is the position of pedestrian i. $\vec{t}_{ij} = (-n_{ij}^2, n_{ij}^1)$ means the tangential direction, and $\triangle v_{ji}^t = \left(\vec{v}_j - \vec{v}_i\right)\cdot \vec{t}_{ij}$ means the velocity difference along the tangential direction. $g(x)$ is a piecewise function defined by

$$g(x) = \begin{cases} 0, & \text{if } x < 0, \\ x, & \text{if } x \geq 0. \end{cases} \tag{6}$$

2.1.3. Interaction force between pedestrian and walls

The interaction force between pedestrian i and walls, $\vec{f}_{iw}$, is similar to Eq. (3) and can be given by

$$\vec{f}_{iw} = A_i \exp[(r_i - d_{iw})/B_i]\vec{n}_{iw} + kg(r_i - d_{iw})\vec{n}_{iw} + \kappa g(r_i - d_{iw})\triangle v_{wi}^{t}\vec{t}_{iw}. \tag{7}$$

Here, d_{iw} is the distance between the center of pedestrian i and the surface of walls.

The parameters of the original social force model are specified in Table 1 [12].

2.2. Modification

Generally, pedestrians' vision field has a direct effect on evacuation. People in front of the current pedestrian often have larger influence than those behind. In this paper, the vision field factor proposed by Helbing [15] is adopted to the socio-psychological force given by

$$\vec{f}_{ij}^{s} = A_i \exp\left[\left(r_{ij} - d_{ij}\right)/B_i\right]\vec{n}_{ij}\left(\lambda_i + (1-\lambda_i)\frac{1+\cos(\varphi_{ij})}{2}\right), \tag{8}$$

where φ_{ij} is pedestrians' visual angle between the walking direction of pedestrian i and the connection direction pointing from pedestrian i to pedestrian j, and $\cos(\varphi_{ij}) = -\vec{n}_{ij}\cdot\vec{e}_i$. $0 \leq \lambda_i \leq 1$, which introduces a non-isotropic influence of pedestrians' vision field. For more details about the vision field in this paper, we refer the reader to Ref. [15].

According to Ref. [16], pedestrians' desired velocity often changes based on his or her nervousness in the course of time, and the parameter $n_i(t) = 1 - \frac{v_{id}(t)}{v_i^0(0)}$ is used to reflect this nervousness or impatience, where $v_{id}(t)$ is the projection value of the velocity at the desired direction, and $v_i^0(0)$ is the original desired velocity. Then, the desired velocity is updated by $v_i^0(t) = (1 - n_i(t))v_i^0(0) + n_i(t)v_i^{max}$, where v_i^{max} is the maximum desired velocity. In reality, however, the excitement or nervousness is not only impacted by the realization degree of desired velocity itself, but also influenced by the people around and also the surrounding environment.

In this paper, we propose a modified time-dependent parameter to reflect the motivation or excitement given by

$$e_i(t) = \chi_1 \cdot g\left(\frac{v_i^0(t) - v_{id}(t)}{v_i^0(t)}\right) + \chi_2 \cdot g\left(\frac{\bar{v}_o(t) - v_i(t)}{\bar{v}_o(t)}\right) + \chi_3 \cdot \xi(t). \tag{9}$$

Here, χ_1, χ_2 and χ_3 are positive constants between 0 and 1, and $\chi_1 + \chi_2 + \chi_3 = 1$. $g(x)$ is a piecewise function defined by Eq. (6). The first term in the right hand side of (9) reflects the effect of realization degree of desired velocity on pedestrian's motivation. $\bar{v}_o(t)$ is the mean velocity of people who are in the vision field of pedestrian i in our simulation. If pedestrians within the valid influence domain of pedestrian i have a larger average speed than that of i, the current pedestrian i who becomes nervous or excited will accordingly increase his or her desired velocity. $\xi(t)$ is the effect of the surrounding environment such as annunciators or displayers on the motivation or excitement of pedestrian i. If the displays show the current situation very dangerous, pedestrians might increase their motivation. It is assumed that $\xi(t)$ randomly distributes between 0 and 1 in this paper.

The desired velocity is then updated by

$$v_i^0(t) = (1 - e_i(t))v_i^{min} + e_i(t)v_i^{max}, \tag{10}$$

where v_i^{min} is the minimum desired velocity. In this paper, v_i^{min} is set to 0.6 m s^{-1} and v_i^{max} is 2.4 m s^{-1} according to Weidmann [20].

3. Guided crowd dynamics

It is assumed that a pedestrian group with guide has no information of the position of exit except for the guide in emergencies within large-scale public places. In this emergency situation, pedestrians should make decisions immediately and definitely choose to follow the guide instead of walking independently without any goal. Naturally, the desired direction of pedestrians will change to guide since they think the situation is fully visible to the guide in the group, who is supposed to convey information to pedestrians by his or her actions.

3.1. Navigational force for pedestrians

The navigational force mostly occurs to the guided crowd within large-scale public places during emergencies. Usually, some or all pedestrians in the group could know the information of the guide. In this paper, as an assumption, each pedestrian can obtain the knowledge of guide r reflected by the navigational force, $\vec{f}_i^r$, which is given by the following expression but not the unique valid choice:

$$\vec{f}_i^r = \alpha_i \cdot m_i \cdot [-b_1(\vec{r}_i(t) - \vec{r}_r(t)) - b_2(\vec{v}_i(t) - \vec{v}_r(t))], \quad b_1, b_2 > 0, \tag{11}$$

where b_1 and b_2 are all positive constants reflecting the weights of navigational feedback. Generally, each pedestrian has his or her own ability to follow the guide including both position and velocity, which is reflected by the size of coefficients b_1 and b_2. If pedestrians can get the guide's information, then $\alpha_i = 1$, otherwise $\alpha_i = 0$. It is assumed that all pedestrians could know the information of the guide for simplicity in this paper, that is, $\alpha_i = 1$ for $i = 1, 2, \ldots, M$.

3.2. Modeling for pedestrians

Pedestrians in the group, due to the lack of escape information, would choose to follow the guide who knows the position of exit. An informed pedestrian is not only affected by the action of the guide but also influenced by pedestrians in his vision field. The model for pedestrians in the group with guide based on the modified social force model proposed in the above section is accordingly changed into

$$m_i \frac{d\vec{v}_i(t)}{dt} = \beta_i \cdot \vec{f}_i^0 + \sum_{j(\neq i)} \vec{f}_{ij} + \sum_w \vec{f}_{iw} + \vec{f}_{ir} + \vec{f}_i^r, \tag{12}$$

where $\beta_i \in [0, 1]$ which reflects the degree of pedestrian's willingness to follow the guide. The desired force $\vec{f}_i^0$ can be expressed by

$$\vec{f}_i^0 = m_i \frac{v_i^0(t)\vec{e}_i^0 - \vec{v}_i(t)}{\tau_i},$$

where the desired direction of pedestrians, $\vec{e}_i^0$, points to the guide before they could see the exit, and the value of desired velocity, $v_i^0(t)$, is updated by Eq. (10). The modified interaction force between pedestrians i and j, $\vec{f}_{ij}$, is denoted by Eqs. (3), (5), (8). $\vec{f}_{ir}$ is the interaction force between pedestrian i and guide r.

3.3. Modeling for the guide

The guide in a group, who provides information to pedestrians in the group, plays an important role for an effective evacuation. However, in a real evacuation, the guide's motion is also influenced by pedestrians around in his or her vision field. Modeling for the guide in a group, which is still based on the modified social force model in the above section, can be expressed by

$$m_r \frac{d\vec{v}_r(t)}{dt} = \vec{f}_r^0 + \sum_j \vec{f}_{rj} + \sum_w \vec{f}_{rw}, \tag{13}$$

where the desired force, $\vec{f}_r^0$, can be expressed by

$$\vec{f}_r^0 = m_r \frac{v_r^0(t)\vec{e}_r^0 - \vec{v}_r(t)}{\tau_r}.$$

Here, the guide moves with a variable velocity according to the surroundings, whose desired direction $\vec{e}_r^0$ is to the exit and $v_r^0(t)$ is updated by Eq. (10). The modified interaction force between pedestrians r and j, $\vec{f}_{rj}$, is also denoted by Eqs. (3), (5), (8).

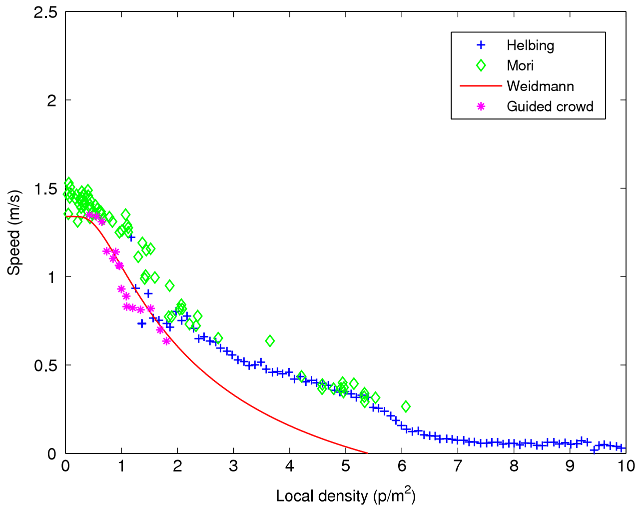

Fig. 3. Pedestrians' density and speed.

4. Simulation

The main challenge for the simulation of guided crowd dynamics is to calibrate parameters to make the movement of pedestrians in a group real. In this section, we are first going to calibrate and validate the guided crowd model, then study different behavioral effects for the group with guide, and also to investigate the effect of time-dependent desired velocity on evacuation.

4.1. Model calibration and validation

There exist four parameters χ_1, χ_2, χ_3 and β_i in the desired force, and two parameters b_1 and b_2 in the navigational force required to be calibrated. The frequently-used regression analysis method has become invalid for the lack of data. In this paper, simulations are carried out repeatedly for finding the suitable values, associated with perception and actual evacuation scenarios. Meanwhile, the criteria for choosing these parameters should also be considered, such as the navigational force should not be larger than the repulsive force or make pedestrians' velocity not correspond to reality, or even cause the normal walking to stop or oscillate. Besides, we propose to determine the above parameters based on the local density and flow in persons for calibration to make them meet the fundamental density–flow diagram. It is worth noting that the local density is a function of the number of all persons in the evacuation group and the area of the minimum rectangle containing these people.

Considering all the above criteria, in this paper parameters are set as below for simulation:

$$\chi_1 = 0.6, \qquad \chi_2 = 0.3, \qquad \chi_3 = 0.1, \qquad b_1 = 0.05, \qquad b_2 = 0.05, \qquad \beta_i = 0.6.$$

In addition, it is assumed that all pedestrians' navigational force and desired force have the same coefficient for simplicity during the simulations. Besides, we assume that pedestrians are all randomly generated within the range of 15 m $\times$ 15 m in a room (50 m $\times$ 50 m) during the simulation, and the exit is set at (50 m, 25 m) which is 1 m wide.

The guided crowd group can produce similar diagrams to those fundamental diagrams reported in the literature [20–22] for density up to 1.8 p m^{-2} even though pedestrians in the group do not know the position of exit except for the guide, and also regenerate the general phenomenon that pedestrian's speed decreases with increasing the density of the crowd as Figs. 3 and 4 show. We can also observe a little variation about the fundamental diagrams given by Weidmann [20], Helbing [21] and Mori [22] who all use the empirical measurements to describe the movement of pedestrians in a plane without stairs or bottlenecks, for example, the speed of guided crowd is a little slower than the fundamental density–speed diagram at some points. There are some reasons for that. One is that we set the desired velocity to change with surrounding environments which might cause desired velocity with larger heterogeneity than normal situation. Also, there exist measurement errors of speed and density for the nature of discretization.

4.2. Effects for the group with guide

In the extreme simulation case, there exists a situation that social force is too large to drive pedestrians' speed change fiercely. Generally, people have a maximum speed according to his or her own status. In the emergency situation, pedestrians can walk at 1.5 times their desired speed [23]. In this paper, we assume that pedestrians have the maximum velocity, $v_{max} = 2.5$ m/s which can be realized by some people in emergency. In addition, pedestrians' initial speeds are all assumed to be zero.

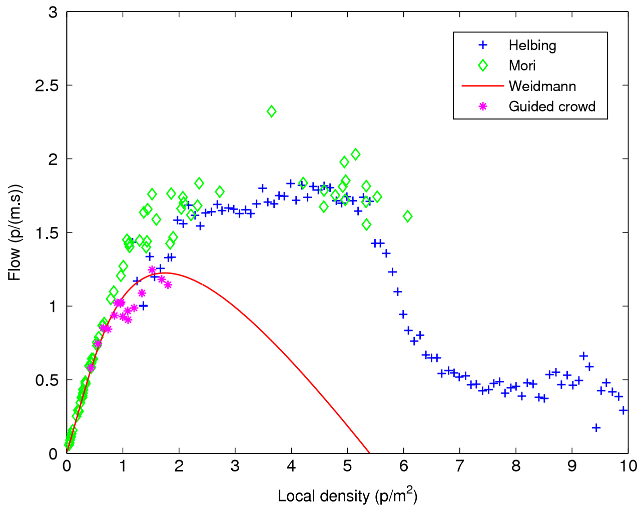

Fig. 4. Pedestrians' density and flow.

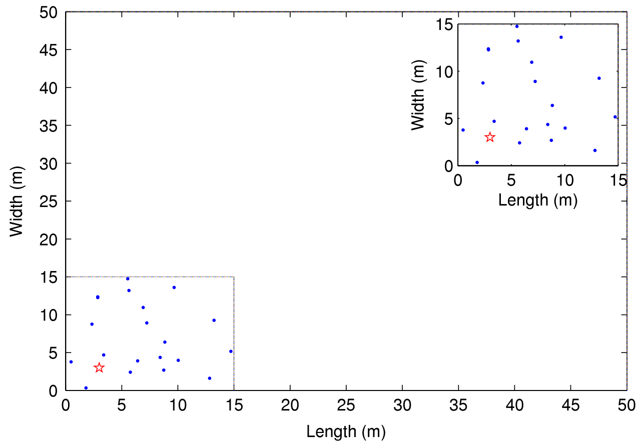

Fig. 5. Initial states of pedestrians and guide.

In simulations, the number of pedestrians is set to 20, and the initial state is shown in Fig. 5. It is worth noting that even if all parameters are set the same, there still exists difference within a certain range allowed for a large number of repeated simulations.

The layout of the simulation scenario is illustrated by Figs. 6–8. Fig. 6 shows that pedestrians intend to gather to the guide, and after a moment, pedestrians develop a quite stable status to follow the guide to escape as shown in Fig. 7. In the simulation, when the distance between pedestrians and exit is less than 10 m, the desired walking direction will be set to exit, and therefore, pedestrians will walk directly to the exit instead of moving toward the guide. At this time, pedestrians are the same with guide who are all driven by the above modified social force model proposed in Section 2. This assumption is easy to be illustrated: consider someone has seen the exit; people around him or her will be informed and know the position of exit because of extremely short distances to the exit; then the informed people will inform others around him or her; naturally, the whole group will know this information. According to Helbing [12], as pedestrians move near to the exit, arching and clogging are observed which are the same with our simulation results shown in Fig. 8.

From Fig. 9, behaviors of pedestrians' movement can be obtained. At the beginning, pedestrians intend to add the speed approaching to guide similar to Fig. 6, and later, the speed relatively keeps fixed similar to Fig. 7. When pedestrians are near to the exit, stop-and-go occurs which is similar to Fig. 8. It is worth noting that in Fig. 9 the x-axis denotes time steps which are the multiple of the size of time step, Δt. In this paper, Δt is set to 0.01 s which considers many factors like avoiding overlapping. Besides, each pedestrian is treated as rotundity in simulations for simplicity whose radius is 0.25 m.

In real scenarios, the scale of layout may be larger than 2500 m^2, and there may be more pedestrians needing to escape in emergencies, when the role of the guide is more important.

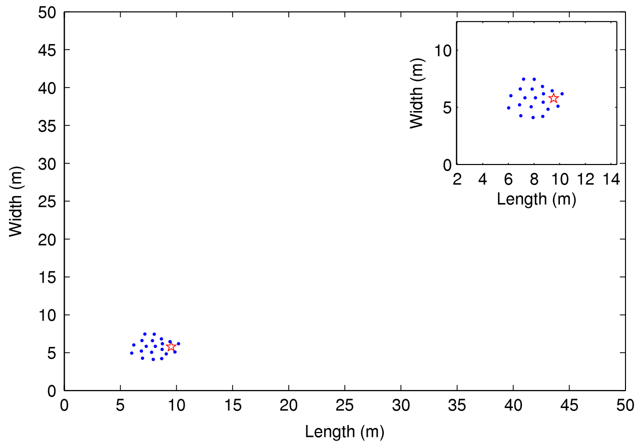

Fig. 6. Pedestrians gather to the guide.

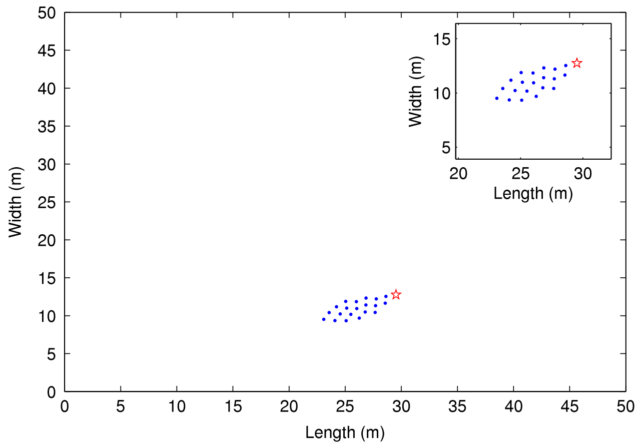

Fig. 7. Pedestrians follow the guide.

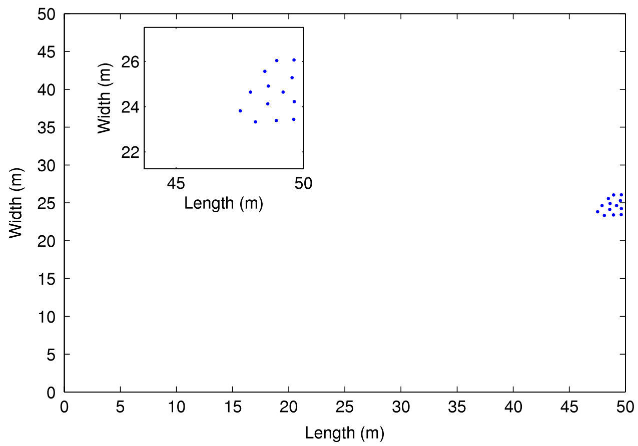

Fig. 8. Arching and clogging at the exit.

4.3. Analysis of desired velocity

Pedestrians' desired velocity in reality always changes because of different factors, such as gender, age or surroundings. Work about the effect of desired velocity on the evacuation is necessary in this paper.

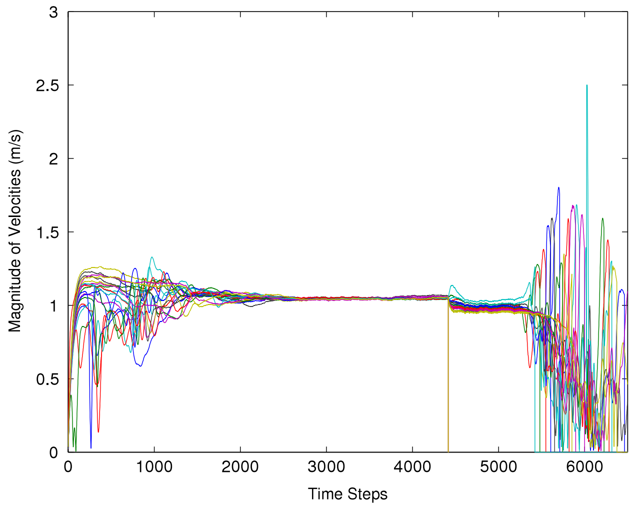

Fig. 9. Magnitude of velocities versus time steps.

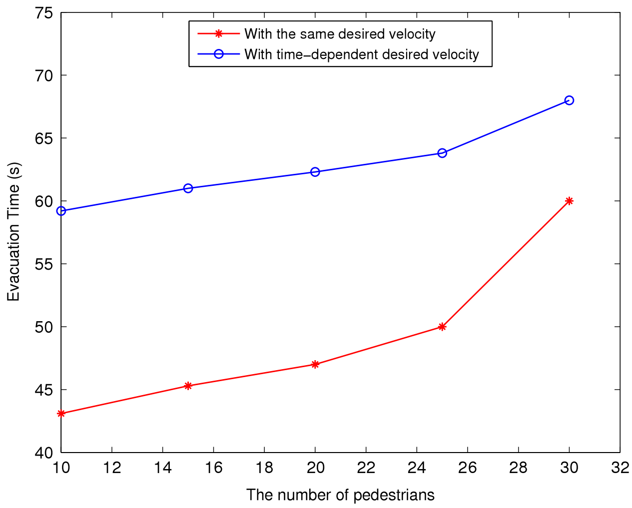

Fig. 10. Pedestrians' evacuation time versus the number of pedestrians.

Fig. 10 shows that time delay occurs to pedestrians with time-dependent desired velocities compared with those with the same. Here, the time-dependent desired velocity for pedestrians is updated by Eq. (10). It can be comprehended that when an old person has a much slower desired velocity than others, he or she cannot reach the average desired velocity which may be higher than his or her maximum velocity. It is natural that he or she is left behind which means that the whole time for evacuation is prolonged as Fig. 10 shows. In this figure, the geometrical scenario and initial conditions keep the same with those in Section 4.1; also the evacuation time for each point is an average value resulting from thirty simulation tests, and the same desired velocity is set to 1.5 m s^{-1}. Besides, when the number of pedestrians approaches to 30, the evacuation time increases faster compared with others, that is because the crowded phenomenon is relatively serious, even if at the beginning, which can be seen from the layout of simulation as Fig. 11 depicts. In extreme cases, after a period of time, the guide and pedestrians walk along the wall instead of heading directly toward the exit as Fig. 12 shows which further extends the evacuation time.

5. Application

Using the guided crowd model proposed in the above section, we do evacuation experiments based on the simulation system of Beijing South Railway Station [24] for multiple pedestrian groups with multiple guides as Fig. 13 shows, where only one guided crowd group could be observed because of the limit of the simulation system itself. Besides, multiple guides are distributed randomly in the station. During the experiment, it is assumed that a terrorist attack occurs in the station, and pedestrians who do not know the route to exits need to escape from the danger following a guide who is closest to him or her and also in his or her vision field.

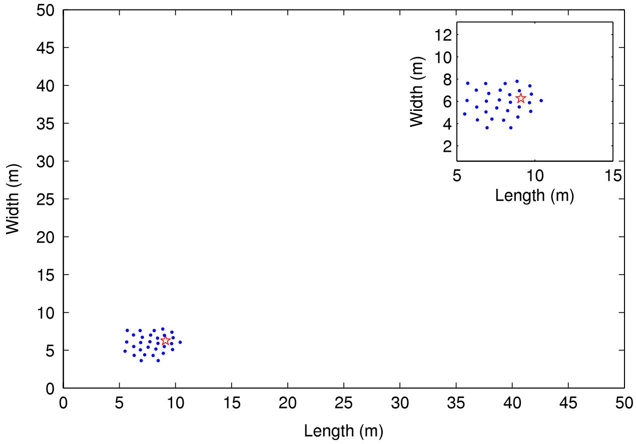

Fig. 11. Crowded phenomenon at the beginning.

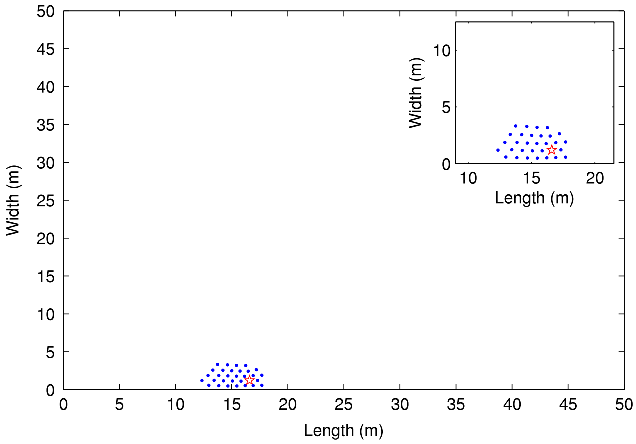

Fig. 12. Pedestrians walk along the wall.

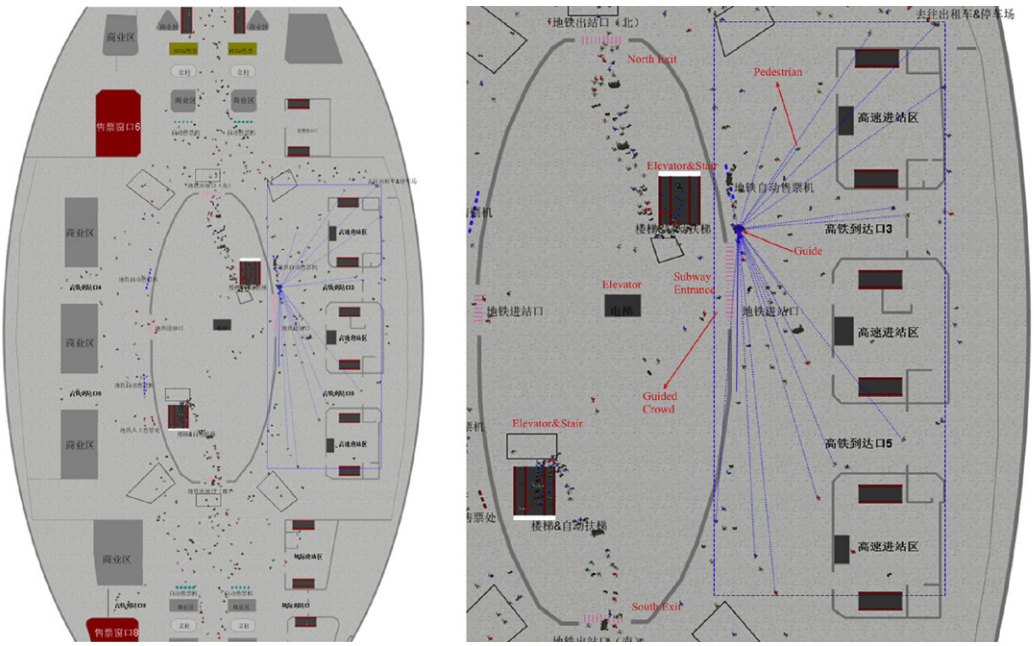

Fig. 13. Diagram of pedestrian evacuation with guides based on the simulation system of Beijing South Railway Station.

Table 2
Simulation experiment results of pedestrian evacuation.

Pedestrian evacuation						
	Without guides			With guides		
Evacuation time	470 s	590 s	720 s	470 s	590 s	720 s
The number of evacuees	451 p	558 p	669 p	676 p	826 p	983 p

Table 2 shows the experiment results of pedestrian evacuation without guides and with guides respectively. From the comparison of simulation experiment results, we can clearly see that the number of successful evacuees in the case of having guides is higher than that without guides within the same evacuation time, reflecting that the evacuation efficiency could be improved by adding the guides who are very important for the actual evacuation.

6. Conclusion

A modification method of pedestrian dynamics based on the social force model is introduced in this paper aiming at making pedestrian dynamics more realistic. Then, the modified model is applied for modeling the guided pedestrian group, where the navigational force is defined. This guided crowd model is validated by comparing its local density–speed and density–flow diagrams with fundamental diagrams. Following it, the effects of the navigational force over pedestrians' walking dynamics are focused on. The phenomenon in emergency, for example, pedestrians in the group who choose to follow the guide instead of walking independently before knowing the position of exit can escape with a larger velocity, could also be reflected from simulation results. Also, the effect of desired velocities on evacuation efficiency is analyzed, from which time delay in the walking group with guide who has time-dependent desired velocities could be found. Finally, we can find that guides would play essential roles for the efficient and orderly pedestrian evacuation through doing evacuation experiments based on the simulation system of Beijing South Railway Station.

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